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a real close look at surfaces

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How would you define a surface? How does such a surface differ from the bulk material? At what distance from the surface, coming from the bulk, are these differences noticeable? How does any oxide layer change the behavior of a surface?

These and many more questions have been asked by many over the last couple of decades --- and are being asked anew in ARL's Surface Chemistry Research group. The nature of the molecular force field surrounding a surface is not well understood despite its fundamental role in such phenomena as heterogeneous catalysis, gas adsorption, the electrical properties of material interfaces, adhesion, friction, and many more.

The properties of clean surfaces (as distinguished form ordinary surfaces which are contaminated by gas and liquid layers) may be important factors in planning prolonged space flights. The ultra-high vacuum of outer space, coupled with possible particle bombardment, is capable of cleaning a surface so that pure metal material is exposed. It is well known that the coefficient of friction of a surface rises an order of magnitude when it is cleaned in high vacuum; cold welding often results. Solid lubricants have recently been developed to alleviate these conditions; they are effective for a year or more --- but what will the more prolonged flights of the future require? If two vehicles couple together in outer space for supply or personnel transfer, what materials can be used that, when perfectly cleaned, will not cold weld and thereby hinder separation?

Surface properties can be changed by radiation --- a matter of interest when nuclear power plants and catalytic life support system components are considered together for future space travel. The mechanisms of heterogeneous catalysis (use of specific surfaces to catalyze specific chemical reactions) are not

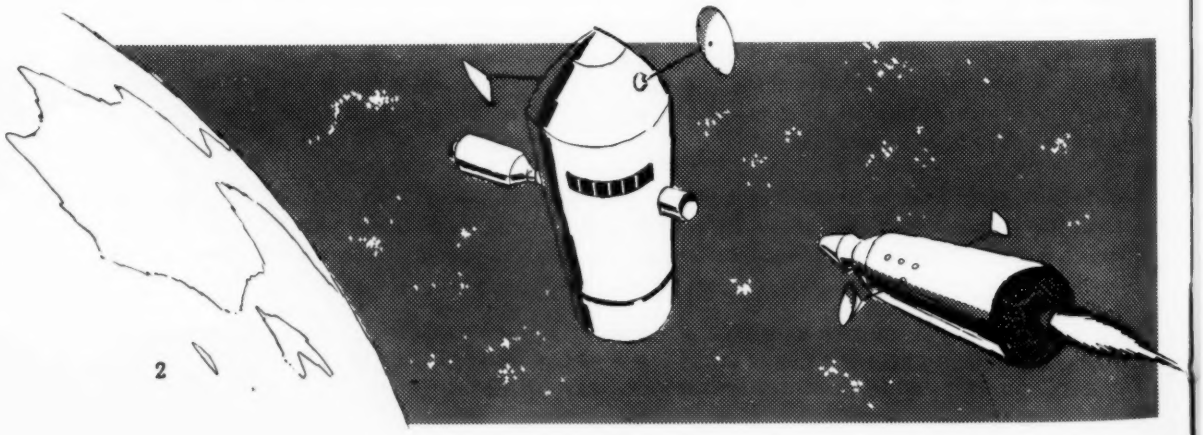
clearly understood; when they are, the technology of catalysis and its subsequent application will be more capable of advancing the development of advanced survival and weapon systems.

Knowing how to tackle specific problem areas that are of interest in the solving of future sufrace requirements entails obtaining a better understanding of the interactions involved. When it comes to surfaces, there is a lot of study still required and, due to the difficulties of obtaining a known surface, this is not an easy job. Surface free energy is a basic parameter used in describing the thermodynamics of interactions, but well defined experimental determination is an area that requires much additional effort, and surface forces, needed in the understanding of the kinematics of interactions, are virtually unknown quantities. The theoretical formulation of surface properties also needs much attention.

A few researchers (Farnsworth, Germer and Mac Rae, Muller, Gomer, Landers and Morrison, and others) have spearheaded the effort to obtain clean surfaces of known structure and have studied a few gas-surface systems. Using many of the techniques of these researchers (low energy electron diffraction, ion surface cleaning, work function determinations), the Surface Chemistry group at ARL will be studying the effect upon basic energy and force parameters of different types of surfaces and surface conditions, including the effect of adsorbed gases.

The most troublesome and essential requirement in surface research is the obtaining of perfectly clean surfaces. Part of the last mono-layer of gas can be very tightly held and must be sputtered off by low energy ions, such as argon, or chemically combined so that the product is easily removed. Low energy electron diffraction is a good analytical tool for indicating both the cleanliness and the order of a surface of the moderate size that is required for fundamental studies. After determining that the desired condition for study has been obtained, a vacuum of 10^{-9} - 10^{-10} torr (mm Hg.) must be maintained; at these pressures, a surface can be studied for periods up to 2 hours before appreciable surface contamination necessitates recleaning. Attaining these vacua is now done at ARL on experimental samples with the aid of good pumping and outgassing equipment (highest vacuum on a system to date . . . . 3×10^{-10} torr.). Gases can be introduced to react with the surface at partial pressures down to 10^{-12} torr. Final development of the analysis systems mentioned is in progress and a start has been made on analyzing single crystal samples.

Now, what about our original question --- i.e., how do we describe a surface? In attempting to answer this, surfaces of well-defined structure will be studied by low energy electron beams to determine the manner in which their electrical field changes as the beam approaches the surface from outside, penetrates it and goes beyond into the crystal. Perhaps some of the mysteries of surfaces can be probed and we can, sometime in the future, begin to know their full potentialities, as well as some of their undesirable effects.



OSCILLATIONS and FLUCTUATIONS in gas discharges

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It is frequently found that oscillations or fluctuations occur when a gaseous conductor (gas discharge tube) is included in an electrical circuit. The oscillations which occur may be divided broadly into two kinds. In the first, the gaseous conductor can be considered as a whole and it usually acts as a non-linear circuit element. In the second, the oscillations are controlled mainly by the internal properties of the gaseous plasma.

In a recent lecture at the Aeronautical Research Laboratories, Professor K. G. Emeleus of the Queen's University of Northern Ireland reported on research (under EOAR Research Grant 62-68) on spontaneous oscillations of the second kind in a beam-generated plasma.

Many of the oscillations detected lie in two frequency bands. One is narrow and for a typical discharge is in the kilomegacycle (gigacycle) region for the plasma electron oscillations. The other band is much wider, with an upper limit of a few megacycles, and has been identified with the ion oscillations.

Various experiments have shown that the directed motion of an initially monoenergetic electron beam in a low pressure plasma (i.e. 1 to 100 microns Hg) may become randomized through the excitation of these plasma oscillations. Interactions of this kind occur for both low voltage (25v) and high voltage (80kv) electron beams.

Under the research grant the beam-plasma interaction in a simple diode is being investigated using Langmuir probe, spectroscopic and radio-frequency techniques. Special attention has been given to the discharge form where there is a quiescent space between where the beam enters the plasma and the place where oscillations and energy redistribution can first be detected. The plasma electron oscillations abruptly attain a large amplitude and appear to be largely confined to a thin layer (frequently meniscus shaped) with some characteristics of a shock front.

The appearance of a discharge with fully developed structure is shown in Figure 1. Here (1) is the cathode sheath (dark region), (2) the beam traversed oscillation-free space, (3) the oscillating sheet or menicus (very bright region), (4) and (5) diverging and converging beams (glow region) to the anode side of the meniscus, (6) the anode sheath and (7) part of the plasma outside the beam. The angle Θ varied between zero and 45^{o} according to discharge conditions. A generally similar structure appears around a cylindrical cathode, but the winging (4), if present, is not apparent.

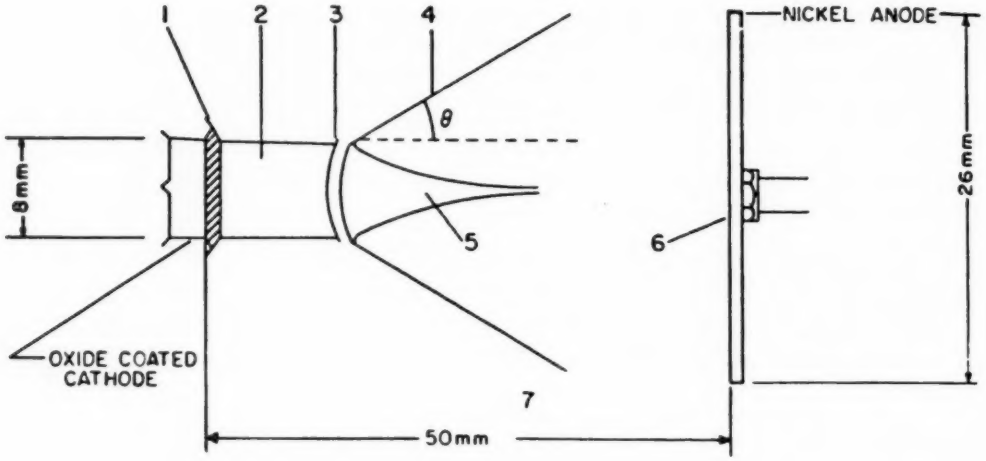

Fig. 1 MENISCUS - TYPE DISCHARGE

The position of the sharp onset of the oscillations along the beam is measured for the appearance of the "spark" spectra in helium, neon, argon and mercury vapor. It has been found to depend approximately on the product of gas pressure, discharge current and beam velocity.

Present work emphasizes the correlation of the high frequency and low frequency oscillations. In particular, it is found that the limiting ion frequency is readily detected in association with the strong electron oscillations near the "meniscus".

Studies are continuing on the importance of boundary conditions and surface wave oscillations.

RESOLUTION OF CYGNUS A

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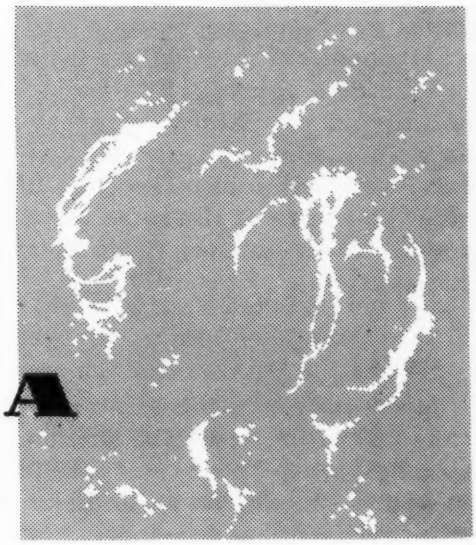


The young science of radio astronomy has expanded from modest beginnings, some thirty or more years ago, into a powerful tool for exploring the universe. The pioneer work of Jansky and Reber in the 1930's stemmed from efforts to discover the cause of and the cure for sources of radio noise in communication circuits using fixed and rotating antenna arrays of various standard types. Radio "noise" was found to come from all directions; some of it was obviously not of terrestrial origin. For instance, they found that radio waves with an essentially continuous spectrum (near the wavelength of 15 Meters) came from the direction of the Milky Way. Discrete sources were found also. One of the early discoveries was a very strong celestial radio source in the constellation Cygnus now called "Cygnus A." It was found to be very powerful indeed; recent calculations indicate that if we could collect and store for future use the total radio energy which it radiates during a one-second interval, our planet's entire heat and power needs for the next trillion years could thereby be filled.

When the discrete radio source in Cygnus was first discovered it was not possible to identify it with any object found in photographs of that region of the sky. The reason for this was that the precision with which a source could be located and its details revealed in general varies inversely with the wavelength employed and directly with the effective aperture of the instrument. Thus, radio tele-

scopes are handicapped in locating sources precisely, in comparison to astronomical telescopes, because of the longer wavelenght which the former employs. The radio waves involved here have lengths of centimeters or meters, whereas light in the astronomical telescope has a wavelength of less than one-ten-thousandth of a centimeter. Thus, astronomical telescopes in general have resolving powers some thousands of times better than that of the largest radio telescope. Nevertheless, radio astronomy yields information not otherwise available.

In recent years the radio telescopes have been improved greatly by the use of paraboloidal antennas or aggregations of elements. The original uncertainty of two degrees in the location of Cygnus A was soon reduced, so as to make feasible a hunt for the object by a large astronomical telescope. When the two-hundred inch telescope at Mt. Palomar was then directed toward the region, two galaxies close together were photographed. The object was faint (18th magnitude). It was found to be unusual, for it is one of a type of objects whose radio emission in comparision to light emission is much higher than that of the normal black body radiation of ordinary stars which behave as thermal sources. In this case the ratio of radio emission to optical emission is about 10^{18} times that of the sun. It was suspected that the intense radio emission was due to some magneto-mechanical processes resulting from the formation of the two parts of the object.

Further improvements in the resolution of radio telescopes permitted the detection of two separate sources in Cygnus A, corresponding to the astronomical photographs. An early measurement at 127 Mc/sec indicated that the two components had an east-west separation of 82 minutes of arc. Later measurements at higher frequencies revealed a greater separation, apparently increasing with frequency.

One way to increase the resolving power of a radio telescope is to use a larger effective aperture. The most powerful example of this is the interferometric arrangement in which signals, received at two or more separated elements of the antenna, are combined to

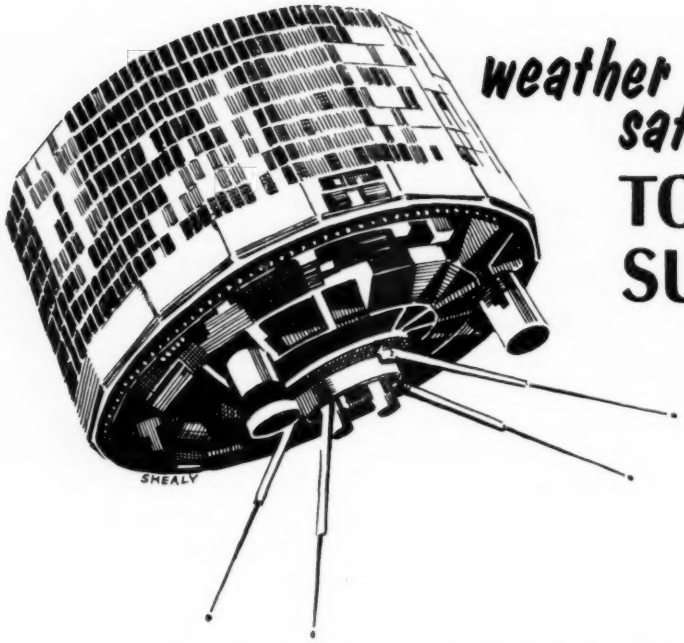
reveal greater detail than would be obtained from one alone. Such instruments are employed at Stanford University, where Professor Bracewell and his colleagues under the sponsorship of the Air Force Office of Scientific Research have employed the narrowest beam width so far attained in radio astronomical observations.

The Stanford instrument is a compound radio-interferometer consisting of sixteen equatorially-mounted, 10-foot paraboloids spaced at 25-foot intervals in an east-west line plus two additional paraboloids in the same line, one at the west end and the second set 325 feet farther to the west. Each paraboloid is a radio antenna so arranged as to receive polarized signals in which the electric vector is in an east-west direction. When the combined signals from the array of 16 antennas is multiplied with that from the two extra elements, the half-power width of the individual beams is narrowed to 52 seconds of arc. In this way precise details of sources are revealed for the first time.

Professor Bracewell and his colleagues report a resolution of the two parts of Cygnus A indicating a separation of 98 minutes of arc at 3292 MC/sec. They further report that the discrepancies in earlier measurements of the separation resulted from inadequate resolution. They now conclude that the two parts of Cygnus A are joined by a central third component whose spectrum differs from that of the main components. Because of the inadequate resolution, the separation of the two outer components appeared to vary with the wavelength employed in the measurement. The narrow beam width of the Stanford instrument has thus provided the explanation for the previous discrepancies in observations.

The high resolution now available will permit more detailed examination of other interesting radio sources. Information of this kind when combined with the results of observations in the optical region of the electromagnetic spectrum, will add measureably to our understanding of astrophysical processes.

The recent results obtained at Stanford will shortly appear in the Astrophysical Journal.



weather satellites: TOO MUCH SUCCESS

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Can an experiment be too successful? Meteorological satellites have come close to achieving this distinction. One of the great surprises of the space age was the quality of the data transmitted by the first Tiros satellite in the spring of 1960. From our new perspective 400 miles in space, it did not take long to realize that conditions existed in the atmosphere which were never before suspected. Just knowing the location of clouds, especially over remote and isolated areas such as oceans, proved to be useful to the weather forecaster and flight planner. Very rapidly, there developed a demand for satellite information on an operational basis. This demand was met with five more satellites over the following three years, with bigger and better satellites to come.

It all sounds very successful; and it is, except that the technology of building and launching satellites outstripped the technology of handling the data after it reached the earth. These satellites, transmitting their pictures methodically and with a single-minded devotion to duty, threaten to engulf the analyst in a sea of 35 mm film strips. The problem then is to improve techniques for analysis -- and this means increased automation. General Dynamics/Astronautics under AFCRL contract, has evolved several highly effective techniques for the machine analysis of satellite data.

Before looking at these techniques, lets look at the methods now used in preparing satellite photos for operational use. First, the pictures are visually examined. Then a stylized representation of the cloud field with a much degraded information content is prepared. This stylized representation is a cooperative man-machine effort. The video signal from the satellite is displayed on a cathode-ray tube which is photographed. The developed photographs must then be rectified -- that is, they must be geographically located and oriented. Grids for this process are prepared by machine. The information on the photograph must then be transferred to a base map in the stylized format. This is often a subjective process, and the end product will vary with the analyst.

General Dynamics/Astronautics has been investigating the automatic rectification and analysis of meteorological satellite data. Within the framework of their contract, they developed a completely automatic process for "flattening-out" the oblique, foreshortened photographs of the spherical earth to conform with a standard map projection; assembled the individual photographs along the orbit into a continuous mosaic, and superimposed latitude-longitude lines upon this mosaic. This can all be done with the video tape of the satellite's transmission. There is no need to convert this tape into a photograph which is scanned with a photo-optical device to digitize it so it can be ingested by a computer.

They have also developed a first step towards automatic analysis of satellite data. The machine program can continue beyond the mapping stage to compute and plot the amount of cloud cover over the field of the mosaic as it would appear to an observer on the ground. Analysis of clouds result in representations of the cloud fields which are more accurate, more detailed and completed sooner than the stylized representation prepared by hand. Being quantitative, this type of output is amenable to direct statistical and mathematical analysis.

General Dynamics/Astronautics, on their own initative, carried the process one step further. With a small 6 db-gain antenna, they received the video tape transmission from TIROS VI as it broadcast to the readout station at Point Mugu, California. The signal was fed directly into the computer and processed in less than an hour.

IONIZING RADIATION AND MARTIAN LIFE

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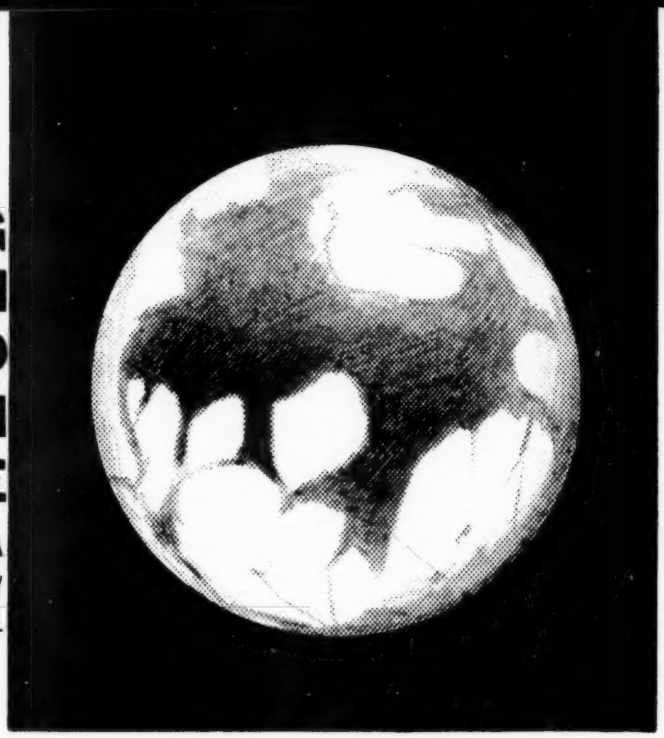

Ionizing radiation reaching the surface of Mars from space may be 80 times as great as radiation on the earth's surface. During brief periods of intense solar proton showers, the radiation on the Martian surface may be a million times as intense as the radiation reaching the earth's surface.

This implication follows from AFCRL experimental and theoretical research conducted by Herman Yagoda on cosmic radiation and was first suggested by Yagoda. It is based on a consideration of the relative atmospheric densities of the earth and Mars, and the known degree of attenuation of cosmic ray particles by the earth's atmosphere. The absorption, scattering and distribution of cosmic radiation in the earth's atmosphere have been intensively measured over the past five years by Yagoda and his group. Balloons, rockets and Air Force satellites have all been used in scores of experiments to measure cosmic ray flux. (Flux refers to the number of particles passing through a given area in a given time from a fixed direction.)

The large amounts of radiation striking the Martian surface has profound implications with respect to life on Mars. Most astronomers agree that life, at least in some primitive form such as mosses or lichens, exists on Mars. If this is true and if large amounts of rad-

iation reach the Martian surface, then the plant or animal life on Mars, subjected over millions of years to high radiation dosages, may have developed considerable immunity to mutations from high radiation dosages. We might expect the evolution of these life forms to have been quite different from the evolution of life on earth--and perhaps to have a different genetic and cellular base structure.

Curiously, the Martian atmosphere, instead of acting as a shield against cosmic and solar ionizing radiation, as in the case of the earth's atmosphere, actually serves to augment the amounts of this radiation reaching the Martian surface. This situation arises as a result of secondary radiation. When a high energy particle collides with the nucleus of an air atom, a number of secondary particles are created in varying number and with varying energies. These particles, in turn, collide with other nuclei giving rise to many more particles -- but with a loss of energy after each collision. Through this process the energy is usually dissipated in the atmosphere before it reaches the earth's surface. Only when a particle enters the atmosphere with extremely high energy does this chain-like collision process persist through a sufficient number of generations to create a radiation dose on the earth's surface. In rare cases a single high energy particle can result in a large radiation shower extending over several square miles of the earth's surface.

Because the Martian atmosphere is only about one-third to one-tenth as dense as that of the earth's, the energy from a given particle is not dissipated before it reaches the surface. Each primary cosmic ray gives rise to a number of secondary particles and these reach the Martian surface with considerable ionizing force. The result is that the radiation hazard from certain secondary components generated by the cosmic rays is actually greater than it would be were Mars to have no atmosphere at all.

This same effect results from high energy protons emitted from the sun during periods of intense disturbance. Although intermittent, the flow of penetrating protons can increase radiation levels by a million times over that found on the surface of the earth. The combination of solar and cosmic radiations reaching the Martian surface is sufficiently high to force man, during a protracted visit to Mars, to shelter himself from the hazard.

ELECTROMAGNETIC ACCELERATION OF TESTING MEDIA

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Present methods of accelerating air to high Mach numbers for test purposes involve the addition of heat to the working fluid in a stagnation region upstream of the nozzle throat. Since the total enthalpy increase here is reflected almost wholly in an increase in translational temperature of the gas, this represents an inherent limitation of wind tunnel techniques because of materials considerations in the stagnation and nozzle throat regions. Due to these restrictions on total enthalpy content, present hypersonic wind tunnels are limited to Mach numbers on the order of 20 - 25 and even in this range flight conditions are only simulated. In order to extend flight simulation to Mach numbers near 40 and realize flight condition duplication at Mach numbers near 20, some means must be found to provide a testing medium of very high total enthalpy.

A very promising approach to a solution to this problem is found in the application of magnetohydrodynamic (MHD) devices used for plasma acceleration. MHD principles are applied to increase the total enthalpy of the working fluid by adding heat and kinetic energy (directed velocity) in the supersonic and hypersonic portions of wind tunnel flows. A study of such an approach is being made by Dr. Eugene E. Covert at the Massachusetts Institute of Technology under Contract AF33(657)-7975. The purpose of this program is to provide information pertaining to the design requirements of a high Mach number plasma accelerator which will provide the proper environment for reentry flow simulation. The altitude range of interest is 300,000 feet to 400,000 feet with a Mach number range from 10 to 40.

The present study is a further development and extension of the traveling wave pump, an electromagnetic accelerating apparatus which, by the application of a moving electromagnetic field, adds both heat and kinetic energy to a previously ionized gas. An alternating current (radio frequency) ionizing unit is presently being considered for use in conjunction with the traveling wave pump

accelerator, since an alternating current discharge minimizes ion bombardment and, hence, reduces the possibility of stream contamination from the walls. Further, the alternating current discharge results in a considerably smaller initial enthalpy at the pump inlet since a nonequilibrium ionized gas is produced. Consequently, for the nonequilibrium mixture, the efficiency of pumping becomes more realistic without giving rise to excessive temperatures, whereas the addition of heat and directed kinetic energy to an equilibrium mixture, ionized sufficiently to give a reasonable conductivity, results in an excessive total enthalpy and excessive temperatures.

A one-dimensional analysis of plasma acceleration by traveling electromagnetic waves has been completed at MIT with the set of differential equations characterizing the traveling wave pump approximated by a one-dimensional steady state form. Approximate integrals have been obtained for the simplified equations and results to date indicate that the viscosity losses in the accelerator will not be excessive, but certain restrictions must be placed on the flow velocity magnitude and distribution at the pump inlet.

The operating principles of the traveling wave pump have been checked in a three-inch diameter test circuit to show the feasibility of the concept. Also, instrumentation consistent with the advancing studies is being developed to measure the basic flow properties (velocity, energy distribution, electron temperature, Mach number, etc.)

In summary, the feasibility of the traveling wave pump concept has been shown and studies are continuing on this electromagnetic acceleration technique, along with studies on the design of an alternating current gas ionizing device and methods of measurement of basic parameters in an ionized flow.

Conceptually, the entire system for the generation and acceleration of a plasma is realistic, and the present approach is promising from the standpoint of possible elimination of the inherent materials restrictions on very high Mach number continuous hypersonic wind tunnels.

the THIRD integral

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For more than half a century investigators in celestial mechanics have put forth new integrals of motion other than the energy and angular momentum integrals. Whittaker in 1916, Cherry in 1924 and more recently (1960) Professor George Contopoulos of Thessalonki University, Greece have been given third integrals.

During 1962 Professor Contopoulos was a visiting Professor at the Research Center for Celestial Mechanics, Yale University, which has AFOSR support. There, he undertook to unify the principal work on third integrals which had been done from different points of view.

In his paper[1], Professor Contopoulos shows that these integrals are equivalent under certain conditions. He discusses different methods for finding these third integrals, explicity calculates a third integral and examines its convergence. Although Siegal gave a proof that the formal third integral does not converge, Professor Contopoulos shows that if it is represented by a Hamiltonian in the form of a polynomial or series, it can be approximated to any degree by another Hamiltonian with converging integrals.

Numerical results provide ample evidence of the existance of the third integral in quite general potential fields as in Schmidt's model of the Galaxy, in the field of the oblate Earth and in potential fields that do not have a plane of symmetry.

There are many cases where a third integral of motion may be applied. One application is to find the boundaries of orbits in the meridian plane of an axially symmetric field. An extension of this is the study of the forms of boundries in almost spherical fields such as slightly elliptical galaxies or the oblate earth. Another application of the third integral is in the study of the stability of periodic orbits.

Professor Contopoulos also points out a general practical method for searching for integrals, by calculating a number of orbits in a given potential field, and examining the space in which they lie. Then one can deduce the existance of a new integral if the orbits do not fill the permissible space completely.

1. Contopoulos G, On The Existence of a Third Integral of Motion, Astron. J., Vol. 68, No. 3, Feb., 1963.

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